Title: Changing Requirements For EW Threat Simulation

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Track: SOS TSG

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1. Introduction

This paper represents my own observations based on recent procurement and contract activity engaged in by Amherst Systems. It is not the result of a scientific survey. No requirement is intended to be associated with a specific system under test or program. These observations are based on many recent requests for proposals and contracts which Amherst Systems has been exposed to. As a leading manufacturer of EW threat simulators for all applications (RWRs, Jammers, ELINT receivers, etc.), Amherst Systems is in a unique position to be aware of many current and future requirements. While we have not won every contract, we have had the opportunity to bid on every major program and thus have been exposed to the most stringent simulation requirements.

1.1. A Few Basics

An EW threat simulator performs three basic functions. The first step is the generation of the radar's transmit waveform. This requires the generation of an RF waveform with the appropriate PRI, frequency, pulse, and scan characteristics. This waveform represents the RF signal as it leaves the transmit antenna. The second function is the modeling of the environmental effects as the waveform travels from the transmitter to the receiver. This model takes into account all factors which affect the electromagnetic wave as it travels from the transmit antenna to the receive apertures on the system under test. The final step is to model the aperture and receiver effects as the waveform is measured by the system under test.

2. Early Simulation Technology

In the infancy of the EW threat simulation industry, there were a few basic requirements to be met. Pulse train generation consisted of simple PRI and pulse width. Geometry and motion simulation was limited to simple straight and level flight in a flat earth environment updated at 1 Hz. A basic radar range equation was used, resulting in a simple 20 log R range loss. The RF signals were typically generated using noisy VCO RF sources with coarse frequency resolution. Modeling of the system under test was implemented by a generic receiver model which generated 4 amplitude controlled signals for injection into an amplitude comparison DF receiver. While all of this may sound quite limited by today's standards, it represented the state of the art at the time. It was also sufficient given the level of sophistication of radar warning receivers at that time.

3. Factors Pushing EW Threat Simulator Requirements

In today's environment, there are several factors pushing the industry to higher performance levels. In recent years, many new simulation requirements have been imposed as a result of the increasing capabilities of the radar system being simulated. Other requirements are driven by increasing sophistication of the EW systems being tested. Another contributing factor is the need to do more testing with smaller budgets. Fortunately, advances in the state of threat for both

digital processing and RF signal generation is advancing rapidly enough to allow threat simulator manufacturers to keep pace with ever increasing requirements.

3.1. Threat Radar Developments

In general, a great deal of work has been done to keep pace with the increasing capabilities of threat radar systems. Recently, there has been much interest in correctly simulating the latest multifunction radars. These types of radars typically use electronically scanned arrays which allow pulse-to-pulse beam pointing changes for the tracking of multiple targets while searching for new ones. Each beam position can have complex PRI patterns or pulse bursts and the changing PRI waveform must be synchronized to each beam position. Other modern radars use complex pulse coding, non linear FM, or phase coding to enhance detection and tracking capabilities. These requirements are currently being addressed and high fidelity simulations of these characteristics are readily available.

3.2. System Under Test Developments

There are many areas where recent developments in the capabilities of the EW systems under test are creating new or more stringent requirements for threat radar simulation. As the EW systems increase their measurement and processing capabilities, there are corresponding increases in requirements for threat simulation.

3.2.1. Increased Receiver Sensitivity

Receiver technology advances have resulted in increased receiver sensitivity for the systems under test. To provide a suitable test environment, a threat radar simulator must maximize the dynamic range of the RF output. The noise floor of the RF subsystem is dictated primarily by the noise floor and dynamic range of the RF source. Digitally Tuned Oscillators (DTOs) typically have lower noise floors and greater dynamic range than synthesizers. Manufacturers of both types of signal sources have recently reduced the noise floors of their sources. There have also been reductions in the phase noise, which new receivers are more sensitive to.

The RF chain used to modulate the generated waveform for transmit scan, range loss, and receiver antenna pattern must balance the distribution of component losses and amplifier gains to preserve as much of the original dynamic range as possible. The utilization of integrated RF components, consisting of amplitude or phase modulators, switched filters, and amplifiers allows the distribution of the gain to be optimized. After the dynamic range of the signal has been maximized, it must be properly positioned by tuning the maximum output power level. In the past, the emphasis was on providing maximum output power. Recently, there has been more emphasis on lowering the noise floor, at the expense of a reduction in maximum output power. As receiver sensitivity increases and the measurement capabilities of the receiver improve, EW systems are being tasked to perform additional functions where the lower noise floor is of greater importance than higher output power. (In some cases, special EW simulator test configurations are used to perform high power saturation of receiver front ends.)

Increased receiver sensitivity also results in higher emitter/pulse density requirements. The lower sensitivity allows the receiver to detect emitters at greater ranges, bringing more signals into the field of view. In addition, more sidelobe and backlobe pulses will be detected. This requires more emitter pulse generation capability in the digital generation subsystem. Distant emitters must be fully simulated to maintain coherency, even though there may only be a limited number of pulses from the main beam which are above threshold. Increased pulse density also requires more channels in the RF generation subsystem.

3.2.2. Sophisticated DF Systems

Major improvements are being made in the DF measurement techniques and capabilities of modern EW systems. Several simulation enhancements are required to provide adequate testing of these new capabilities.

3.2.2.1. Improved Motion Models

The geometry updates for platform motion increase as EW receivers measure angle of arrival to greater accuracy. In order to avoid having an emitter jump more than one angle cell between motion updates, geometry calculations must be performed at higher rates. In some cases, motion and angle of arrival modulation must be updated at rates as fast as 1000 Hz. In addition, a full 6 degrees of freedom is required to provide a proper angle simulation as an aircraft performs highly dynamic maneuvers. Testing the ability of an EW system to maintain emitter tracks during such maneuvers requires highly accurate motion models.

3.2.2.2. Doppler Modeling

Some newer EW systems utilize Doppler effects to measure angle of arrival through the use of sophisticated processing algorithms. To support testing of this capability, it is necessary to simulate both PRI and RF shifts due to the relative motion of the emitter and system under test platforms. The range delay time changes as the distance between the two platforms changes, inducing small variations in the PRI from pulse to pulse. Simulation of this effect, known as PRI Doppler, requires extremely precise pulse timing in the nanosecond range. The closure rate between the two platforms also generates frequency Doppler. Very high precision RF sources are needed to simulate these pulse to pulse variations in frequency.

3.2.2.3. Simultaneous Phase and Amplitude

Some new receiver systems are making use of simultaneous measurements of relative phase and amplitude at several apertures to compute angle of arrival. Testing this capability requires both phase and amplitude modulation components in the RF path for each receiver port. In addition to the algorithms required to compute both phase and amplitude simultaneously, it is also necessary to account for the incidental phase shift of the attenuator and the incidental amplitude variation of the phase shifter or vector modulator. In systems which require only phase or amplitude control, the incidental effects are not significant. However, when both characteristics must be controlled in the same RF path, these effects become extremely important, especially in light of tighter accuracies needed for compatibility with current receiver capabilities. Compensation for these effects requires sophisticated multi-step calibration algorithms.

In addition, new receivers are using increased numbers of apertures to provide more precise angle measurements and to allow multiple functions, such as signal detection and precision direction finding, to be performed simultaneously. To support this, a more modular architecture which provides more parallel processing is required. For a receiver with dozens of apertures, it is impractical to compute all of the required phase and amplitude values at a central point. An added benefit of a more distributed architecture is that the design is more easily scaled to a specific system under test configuration.

3.2.2.4. Polarization Modeling

Some new EW systems are making use of apertures with both vertical and horizontal polarization, rather than circular polarization. Complex aperture modeling is required to properly stimulate each aperture. For each emitter, the polarization orientation of the transmitted waveform must be matched against the vertical and horizontal response of each receive aperture. Figure 1 shows the transmitted wave vectors and receive aperture vectors and how they are combined mathematically.

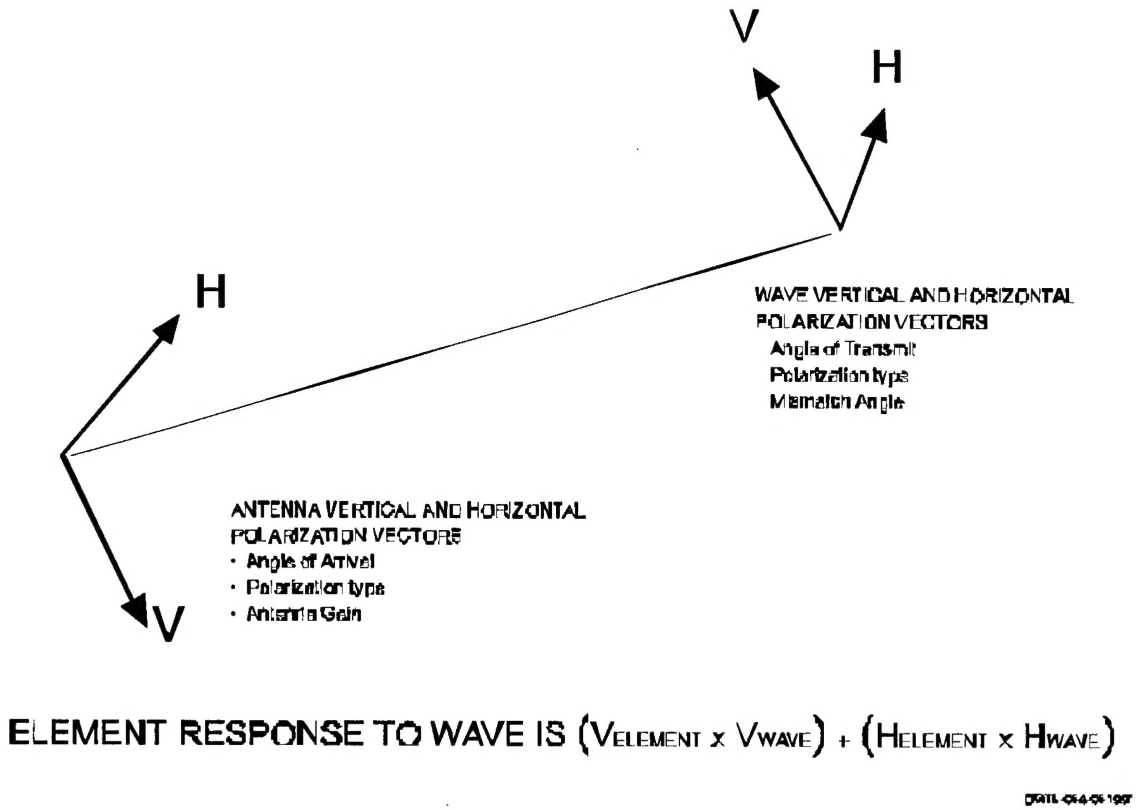

Figure 1

The pulse to pulse orientation of both the transmit and receive platforms must be accounted for in the calculation of the relative orientation of the transmitted waveform at the receive aperture. Figure 2 illustrates how the orientation of the wave relative to the receive aperture is determined.

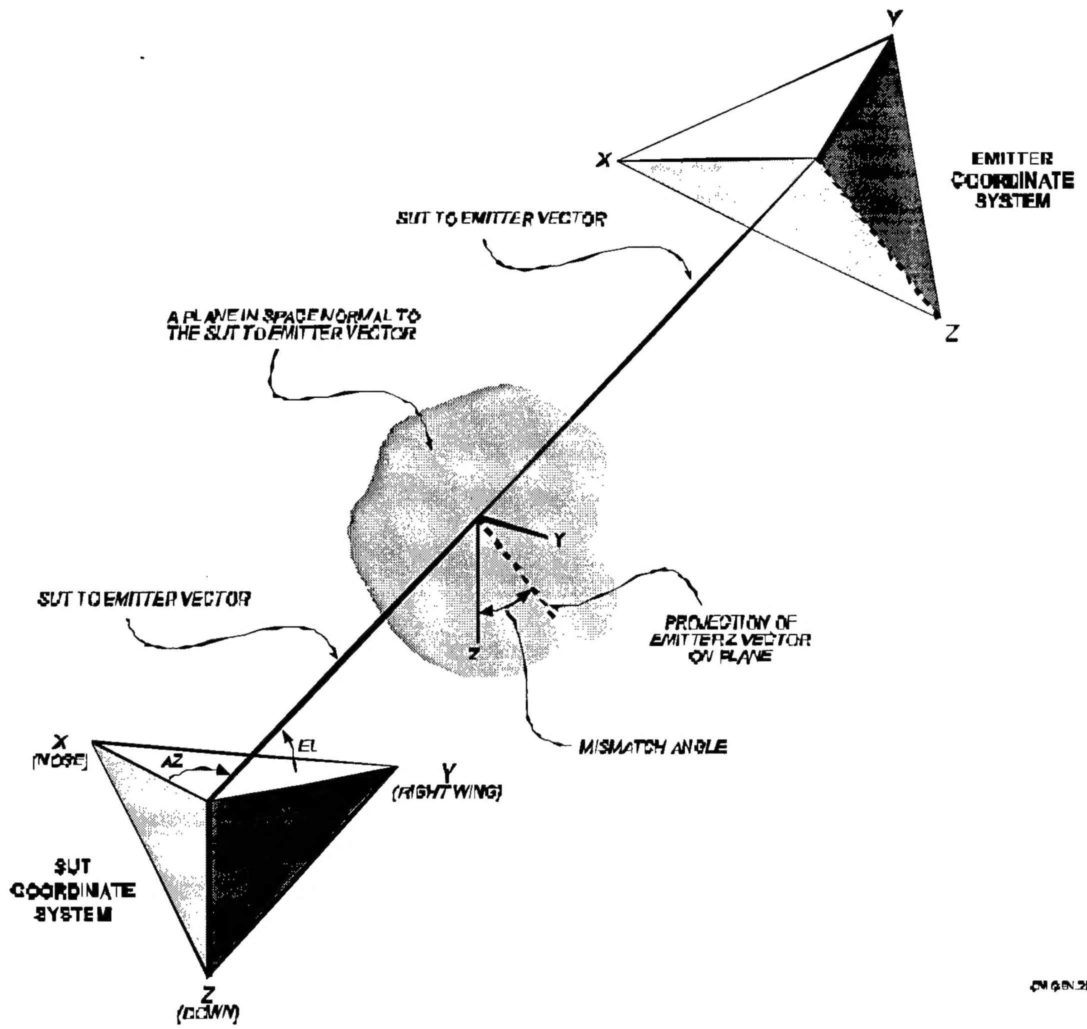

Figure 2

In some cases, measured data shows that transmit polarization varies significantly outside the main beam and this must also be accounted for through the use of a full three dimensional polarization model.

3.2.2.5. Time Difference of Arrival

Another emerging technology is the use of time difference of arrival for direction finding. This requires precise pulse timing control for each receiver aperture. Typically, timing is required to one (1) ns resolution, with a maximum variance from port to port of 150-200 nsec. For normal angle of arrival simulation, the generated pulse is split into several paths, one for each receiver aperture, and then phase or amplitude modulated as a function of the geometry. In this case, the leading edge of the pulse is delayed, leading to corruption of any intrapulse characteristics of the generated pulse. An analysis of the most common intrapulse modulations leads to the conclusion that preservation of bi/quadphase modulation is desirable, and can be included at an acceptable cost. The timing delay from one receiver aperture to another may be large enough that an entire phase modulation bin would be eliminated from the pulse. Systems looking for specific modulation pattern content would detect different patterns at different ports. On the other hand, typical chirp and FMOP modulations are such that elimination of a small portion of the leading edge of the modulation is not significant to the receiver. The same is true of most AMOP

modulations. Of course, the technology to preserve all intrapulse characteristics is available, but at significant cost. For most systems, inclusion of separate frequency and amplitude intrapulse modulation elements for each receiver aperture is not required. Where pulse rise and fall times are controlled for each emitter, this characteristic must be preserved for each receive aperture.

3.2.3. Receiver/Processor Capability

As with many things, the processing capability of EW systems is increasing dramatically. As a result, modern EW systems have increased track file size and are expected to handle environments with higher emitter/pulse densities. Threat radar simulators must be able to provide these additional densities to stress the processing capabilities of these new receiver processor systems. Another application of the increased processing capability is the utilization of precisely measured pulse times in sophisticated algorithms to identify the underlying clock characteristics of a specific radar. In support of this, threat simulators must be able to model crystal count-down techniques for PRI generation with extreme precision and must be able to control pulse start times to one (1) ns or less.

3.2.4. Integrated EW Suites

As EW suites become more integrated, it is necessary to provide threat simulators capable of stimulating apertures for multiple receivers simultaneously. Separate outputs may be required for an RWR, a jammer, and an ESM system. While no one system may have a large number of apertures, taken together, an integrated suite can easily have upwards of 40 apertures. Also, the different systems may use different direction finding techniques, including amplitude, phase, time difference of arrival, or a spinning antenna. The threat simulator must be capable of modeling each different direction finding technique simultaneously for each pulse. A distributed processing architecture again becomes critical to supporting this requirement. In addition, the various subsystems of an integrated suite quite typically communicate with each other over a standard bus. To support development and testing of individual subsystems, it may be necessary for the threat simulator to provide a simulation of bus message traffic. For example, testing a jammer may require generation of message traffic normally provided by the radar warning receiver.

3.2.5. Sensor Fusion

Sensor fusion is a growing element of modern electronic warfare. With Sensor Fusion, there may be several sensors, including a communications receiver, radar, EW receiver, and an IR sensor, which all detect and characterize various target signatures. Higher level software attempts to correlate detections from each sensor in order to increase confidence in target identification and location. A true multispectral stimulus is required to support testing of the fusion algorithms. A coordinated environment, including precise time and motion synchronization must be presented to each sensor. Each player must appear at same time for each sensor, and each sensor must see the player at the same location. There may also be a need for informational synchronization, where signatures with message content accurately represent the environment being simulated. This requires the ability to program a common scenario for all of the stimulators, and each stimulator must be capable of accepting precise time synchronization from a master control during a real time simulation.

3.3. Multipurpose Laboratories

As laboratories are consolidated, there is a growing need for a single laboratory to support multiple systems under test. It is no longer cost effective to have simulator systems configured to support a single receiver configuration. The simulator must provide reconfigurable test assets which can be rapidly reprogrammed to provide phase, amplitude, or time difference of arrival modulation for each output port. In addition, it is desirable to have a flexible architecture where the interconnection of RF generators and angle of arrival modulation assets can be changed to provide a higher channel density with fewer output ports, or higher number of output ports for a

reduced number of channels. This allows a laboratory to be readily configured to meet changing test requirements and receiver configurations.

3.4. Training Applications

Training applications for EW threat simulators are expanding rapidly. There is growing interest in stimulating real avionics rather than modeling the function of the avionics in a trainer. This is true for both on board trainers for ships and classroom trainers. Software models of an EW system require extensive validation and constant updates as the EW system is improved. The use of actual EW system hardware eliminates the validation step, and provides a more realistic training environment. It is not always necessary to stress the processing capabilities of an EW system for a training application, creating a need for smaller simulator configurations which still provide full emitter fidelity. This is especially true for on board trainer systems. Also, digital injection can provide a more cost effective means to utilize actual avionics as part of a trainer. This requires a digital model of the receiver front end, but eliminates the need for expensive RF generation subsystems and also eliminates the need to have the actual system under test receivers present. Distributed training applications also require threat simulators which can support real time control interfaces using Distributed Interactive Simulation (DIS) or High Level Architecture (HLA) protocols.

3.5. Shrinking Flight Test Budgets

Flight test budgets are shrinking, placing more emphasis on laboratory simulation. To support this, there is a need for higher fidelity simulation of environmental factors such as terrain masking, multipath, ducting, weather effects, and wave splashover. All of these characteristics are present in range testing or sea trials. In order to be more reliant on laboratory testing, these environmental effects must be accurately modeled. This provides higher correlation between laboratory results and flight test or sea trial results. As the correlation between the results from the two forms of testing increases, the value of laboratory testing will increase, and more aspects of system performance can be characterized and verified without costly flight testing.

3.6. Range Applications

Modern EW ranges require greater flexibility. There is a need for dual use ranges, which can support both test & evaluation and training requirements. For training applications, it is desirable to have a training range integrated with an EW simulation. For these applications, an EW threat simulator can be used to model the transmit characteristics of a threat radar. A measurement receiver can be used to detect jamming signals from the aircraft being illuminated to support model based reactive emitter control. A major benefit of adapting an EW threat simulator for range use is rapid reprogrammability, where a single threat site can be used to simulate multiple radar sites during a single training exercise or test. To maximize the flexibility of each threat site, wider band transmitters are used, with some tradeoff in output power. This also provides the capability to simulate multiple emitters from a single site, providing a cost effective increase in signal density.

3.7. Support Tools Software Environment Generator

As the capabilities of threat simulators have grown and environment densities have increased, there has been a higher demand for enhanced support tools. A major emerging requirement is the need for automatic dynamic scenario generation. These scenario generation tools allow the user to specify an initial threat laydown and rules of engagement which are then processed by an engagement model. The model may use either a predefined flight path for the system under test platform or it may allow a man in the loop to fly the system under test. As the system under test platform moves through the environment, the engagement model controls emitter activity according to the previously specified rules of engagement. The engagement model facilitates generation of realistic dynamic scenarios and allows multiple flight paths to be analyzed for scenario density and EW system performance.

In the interest of maximizing the utilization of simulator assets, there is a growing need for non-real time signal generation and analysis tools. These tools allow the operator to use a software model to generate a pulse by pulse representation of a scenario and save the results in a disk file. This can be done on a stand alone workstation without tying up the simulator hardware assets. Once the pulse file is created, analysis tools can provide RF signal characterization, density computation and graphical plots of pulse trains which can be used for emitter programming verification. In addition, pulse density analysis tools can be used to predict system throughput, pulse contention and dropout. These predictions can be used in RF configuration and scenario tuning to optimize simulator performance. Figure 3 shows an example of one of the several analysis tools available. This tool calculates a scenario emitter or pulse density as a function of time, frequency, AOA, amplitude or several other user-specified parameters

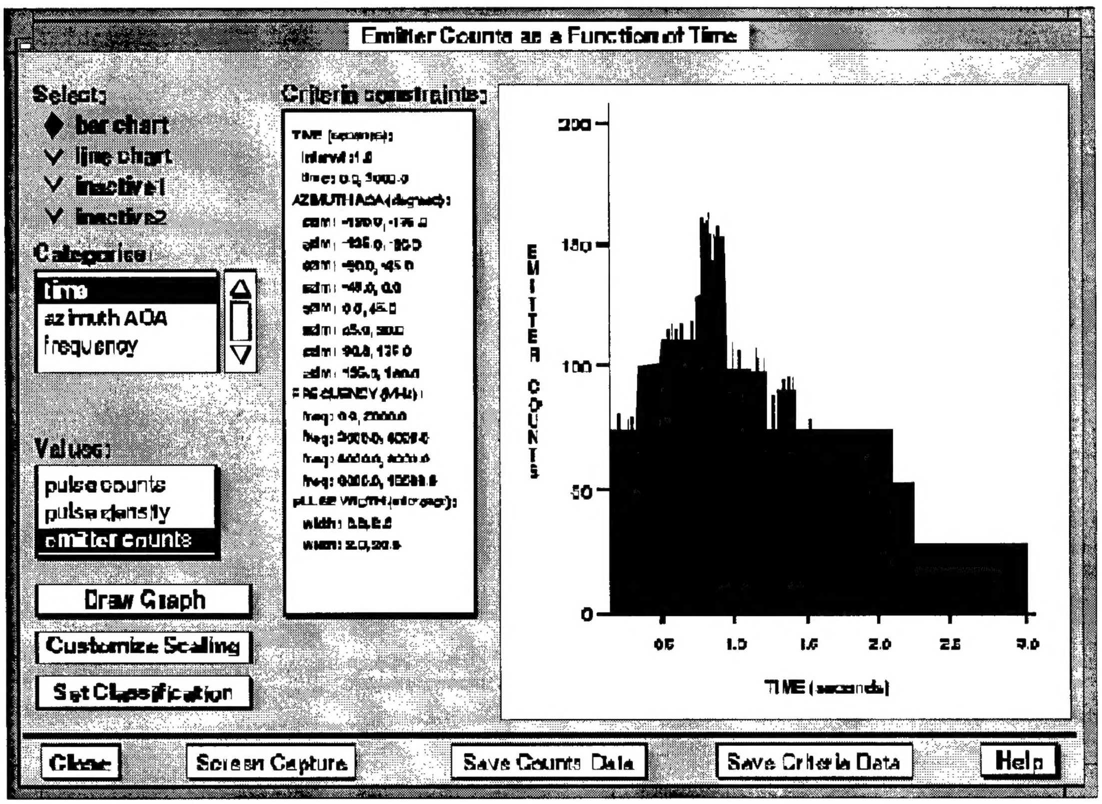

Figure 3

3.8. Integrated Simulator Applications

As laboratory simulations become more sophisticated, there is a need for real time interfaces for laboratory integration. These interfaces may include ownship navigation control, platform control and emitter control. The host processor may be running a higher level SUT simulation or utilizing real time engagement or performance models to generate real time scenario changes. Real time interfaces may also be used to support a man in the loop flight simulator. These types of applications require the threat simulator to react to external inputs in order to provide a truly reactive environment. Other applications require remote scenario monitoring by a host computer. Trainer systems may utilize a real time interface to the instructor station to support real time changes to the training exercise and monitoring of student performance.

3.9. Monitoring and Analysis

There is growing interest in monitoring and analysis tools to aid users in the verification of simulations and analysis of system performance.

3.9.1. Signal Generation Verification

In any test situation, there is a need for "truth" data, a record of the actual test stimulus that was generated. This is needed to verify that the correct emitter waveforms were generated and to monitor simulator performance. Truth data may be recorded in the form of digital pulse descriptor words which can be post processed for performance analysis. This form of data is useful for detailed analysis of pulse train generation and simulator throughput. Another form of truth data is generated by a real time signal measurement system. This system captures, analyzes, and records the actual RF output of the threat simulator. This provides verification of signal generation at the final outputs of the simulator for maximum confidence.

3.9.2. SUT Performance Analysis

When a system under test is subjected to a dense dynamic scenario stimulus, it is not feasible to determine EW system performance manually. There is a need for analysis tools which can automatically correlate the generated stimulus to the characterization of the environment made by the system under test. Truth data recorded by the threat stimulator provides one input to the correlation process. The other input can be provided by re-recording emitter reports or similar data available on standard busses within the system under test. Additional data may be in the form of real time measurement of actual ECM outputs generated by a jammer system. The simulator truth data and recorded system under test data are correlated to determine correctly identified emitters, time to detection, accuracy of measured parameters such as frequency or angle of arrival, missed emitters, and false emitter reports. These results can be analyzed statistically or presented in graphical form to determine quantitative performance of the system under test.

4. Summary

EW threat simulation capabilities must meet ever expanding requirements. These requirements are the result of the increasing capabilities of threat radars and the increasing detection and processing capabilities of EW systems. Other factors influencing emerging requirements include the need for higher fidelity simulation capability to provide closer correlation between laboratory testing and flight testing in order to allow greater reliance on laboratory results. To meet these requirements, a new generation of EW threat simulators must make use of state of the art technologies, including modular scaleable architectures, high speed DSP/RISC processors, and integrated RF subassemblies. Advanced software models are needed for scenario effects including platform motion, direction finding modulation computation, and environmental models. Significant investments by both EW threat simulator manufacturers and users are required to keep pace with these changing requirements.

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